High accuracy and cost-efficient ethernet-based timing system for the IFMIF-DONES facility

Granada, 1th October 2023

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Universidad de Granada

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IFMIF-DONES CONTROL LAB

Remote handling area

Videowall – Mirror Room

LIPAc-DONES area

Lab goal: research about key control technologies for the design and construction of the IFMIF-DONES facility.

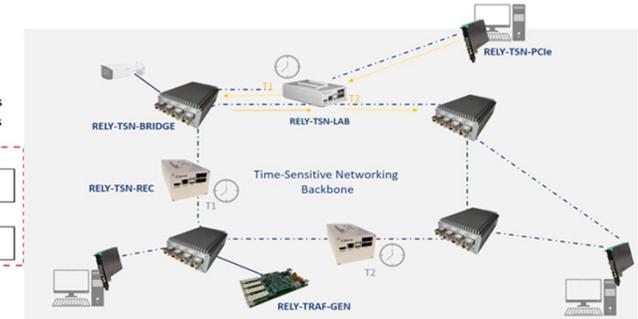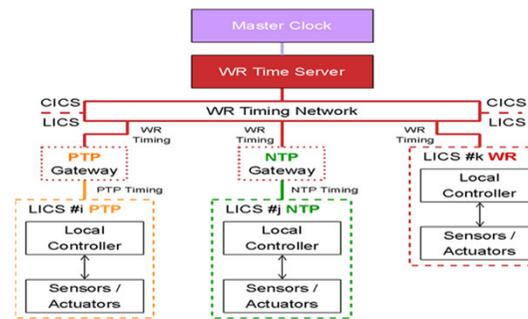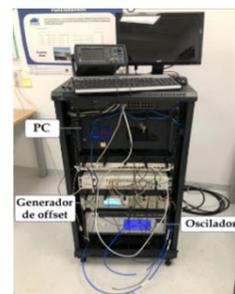**Main topics:** control system requirements and use cases, remote handling robotics and automation, timing and communication, CICS & LICS control architectures, Digital Twin (virtual infrastructure)

EPICS

genRobot

OPC UA

Timing and Communication architecture exploration and setups

Lab's team

Marta Ternero Alberto Ortega Carlos Megías Iván Casero

Elio Valenzuela Abel Cano Víctor Vázquez Javier Cruz

Timing subsystem & network

1 TTP (< 10ns) Estable RF dissemination
IEEE-1588-2019 (or White Rabbit)

2 LTP (50ns - 500ns)
IEEE-1588-2019 (hardware)

3 IP (50us - 1ms)
IEEE-1588-2019 (software) or NTP

3. Site, Buildings and Plant System

3.5.5 LICS of Remote Handling	3.6.5 LICS of Heating, Ventilation and Air Conditioning	3.7.4 LICS of Electric Power System
3.8.3 LICS of Heat Rejection System	3.9.6 LICS of Service Water System	3.10.5 LICS of Service Gas System
3.11.4 LICS of Solid Radioactive Waste Treatment System	3.12.5 LICS of Liquid Radioactive Waste Treatment	3.13.5 Gas Radioactive Waste Treatment System
	3.14.4 LICS of Fire Protection System	

4. Test System

4.2.8 LICS of Test Cell *	4.3.7 LICS of High Flux Test Module *
4.4.7 LICS of Start-Up Monitoring Module *	4.6.8 LICS of Test Systems Ancillaries
4.7.4 LICS of Facilities for Complementary Experiments	

5. Lithium Systems (LS)

5.2.4 LICS of Target System *	5.3.4 LICS of Heat Removal Loops
5.4.4 LICS of Impurity Control System	5.5.7 LICS of Lithium Systems Ancillaries

6. Accelerator System

6.2.3 LICS of Injector System	6.3.3 LICS of Radio Frequency Quadrupole *	6.4.8 LICS of Medium Energy Beam Transport *
6.7.8 LICS of Radio Frequency *	6.6.7 LICS of High Energy Beam Transport *	6.5.6 LICS of Superconducting RF Linac (SRF) *
	6.8.6 LICS of Accelerator Systems Ancillaries	

8. Central Instrumentation and Control Systems

8.2.1 Supervision & Central Control Subsystem	8.2.3 Data Management Subsystem	8.2 CODAC *
8.2.5 Alarms & Warnings Subsystem	8.2.6 Control and Data Communication Subsystem	8.2.4 Central Control Room Equipment and Human-Machine Interface Subsystem

8.3 MPS *

8.3.1 Central Interlock Subsystem

8.4 Safety Control System SCS *

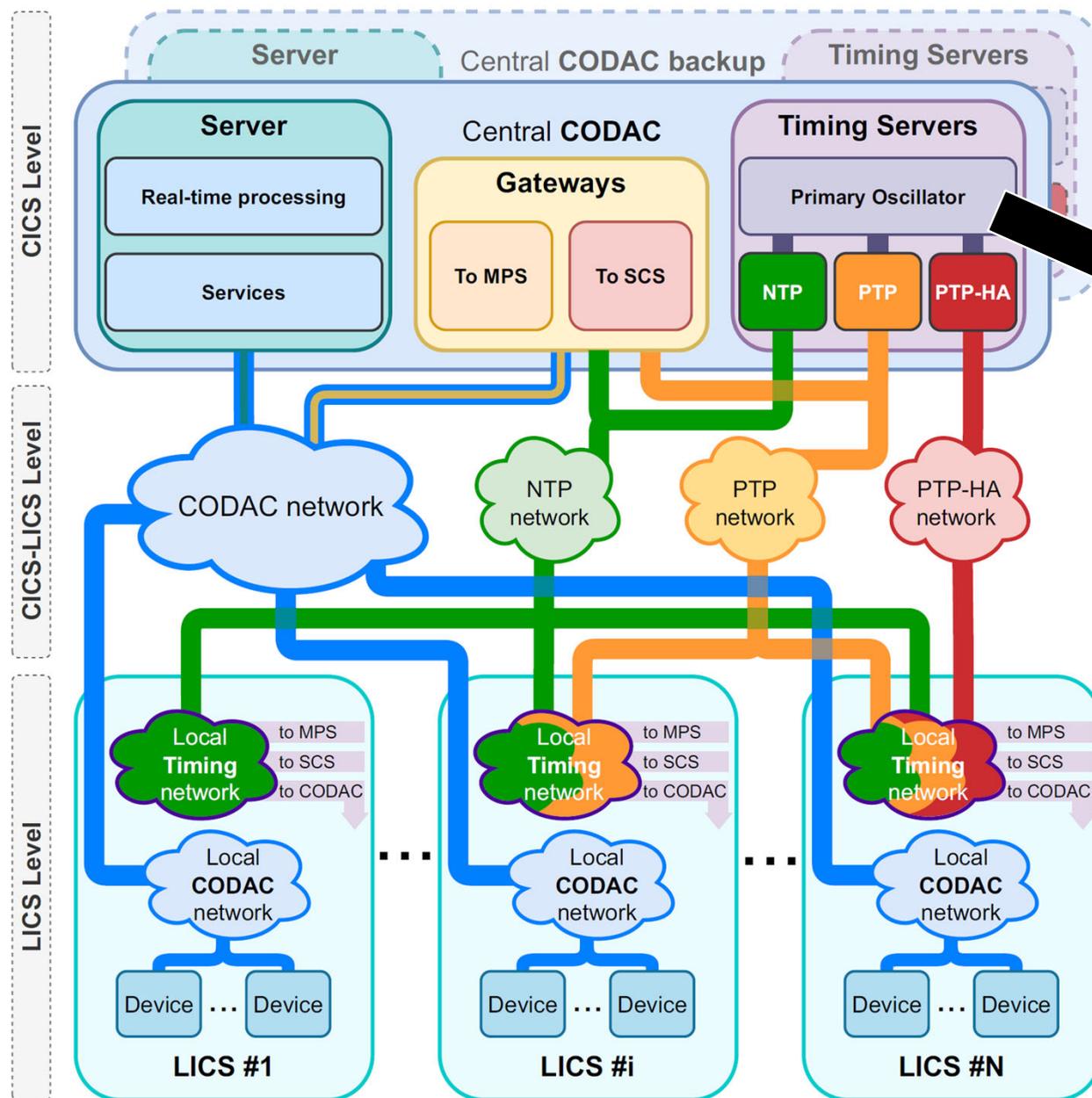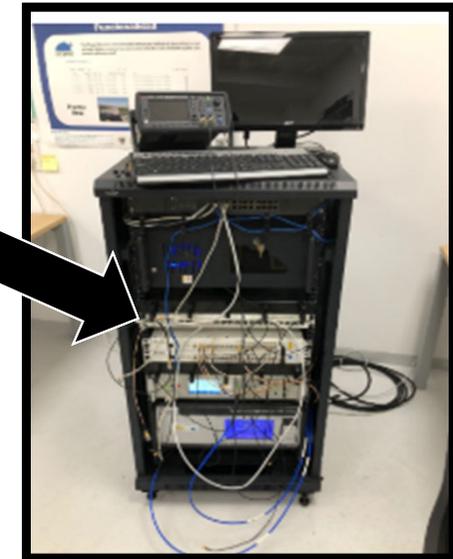|	
8.4.1 Plant Safety Subsystem	8.4.3 Personnel Access Safety Subsystem

Timing requirements

- Performance: time transfer (1ms, 1 us) and RF dissemination (<1ps phase noise)
- Resilience (redundant topologies)
- Deterministic performance (minimal PDV)
- Interoperability (Ethernet), no calibration, monitoring, …
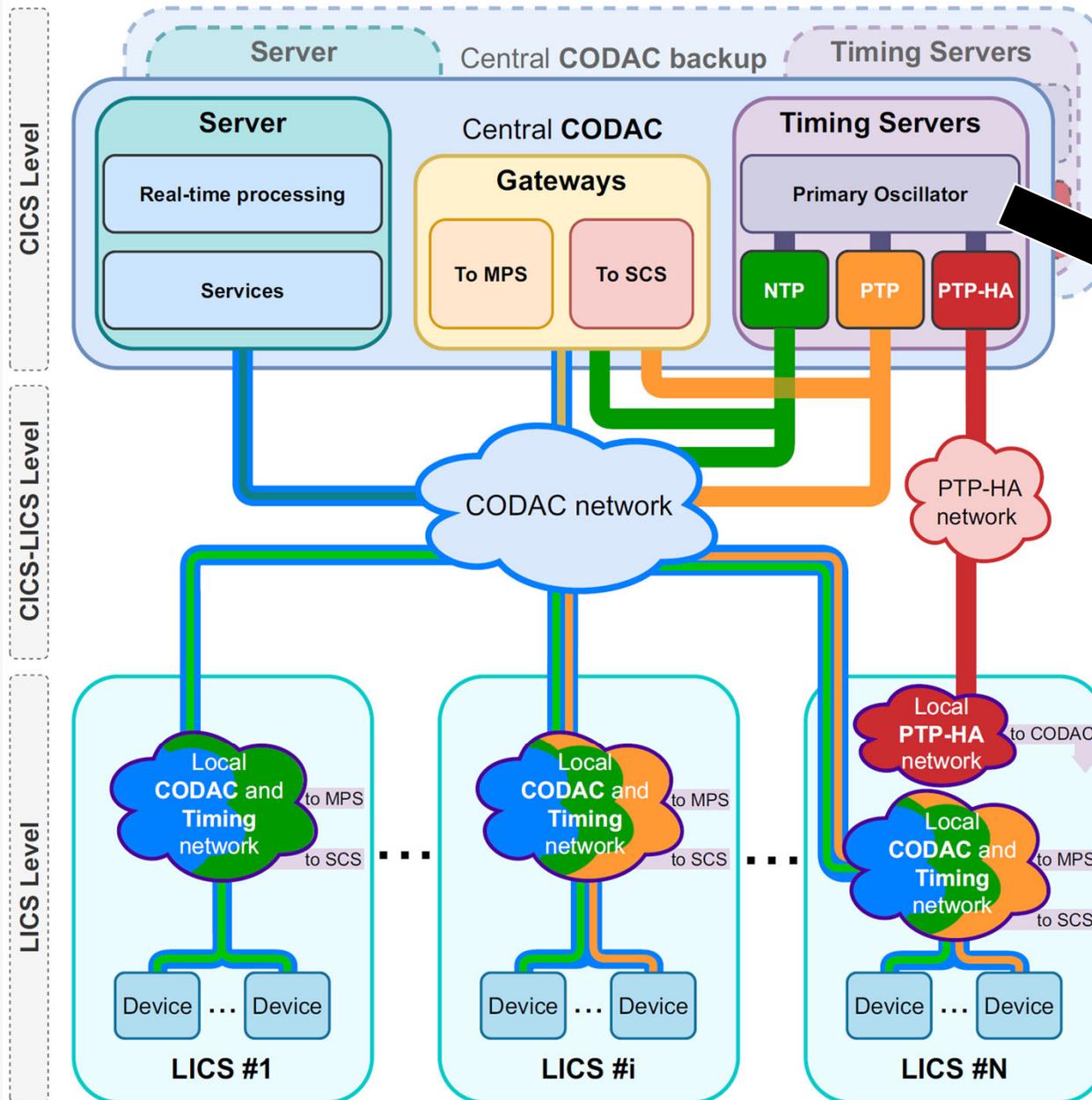
Sol. Independent networks
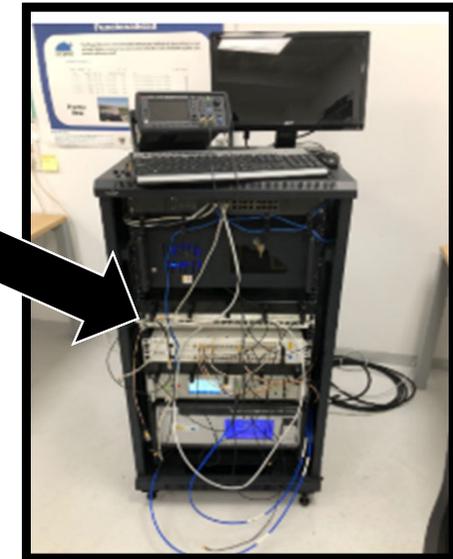

- **Master clock**

- One dedicated network per time protocol.
- No shared medium with data network
- Expensive but easy

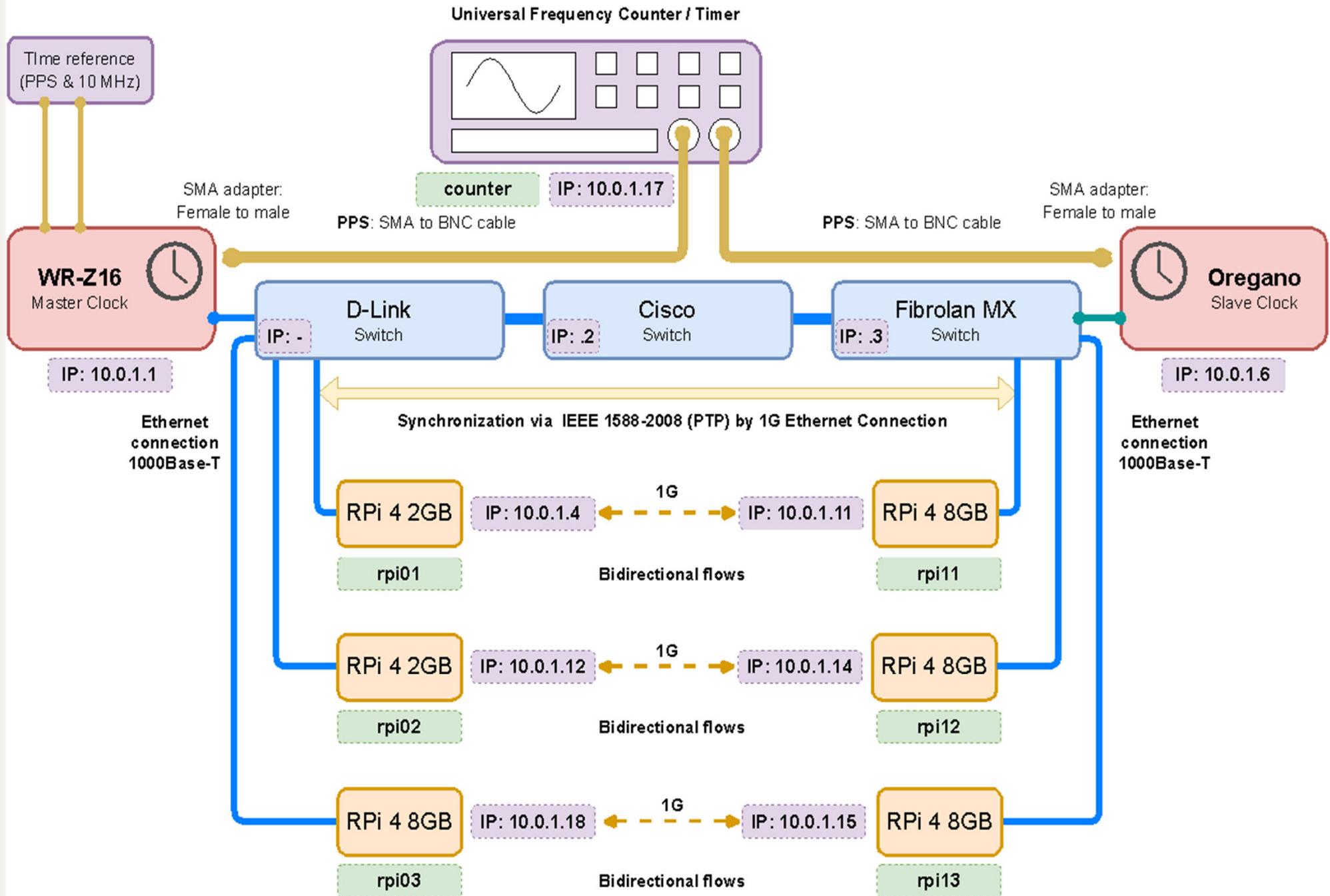# Sol. Data & timing networks

- **Master clock**

- One dedicated network for HA (WR)
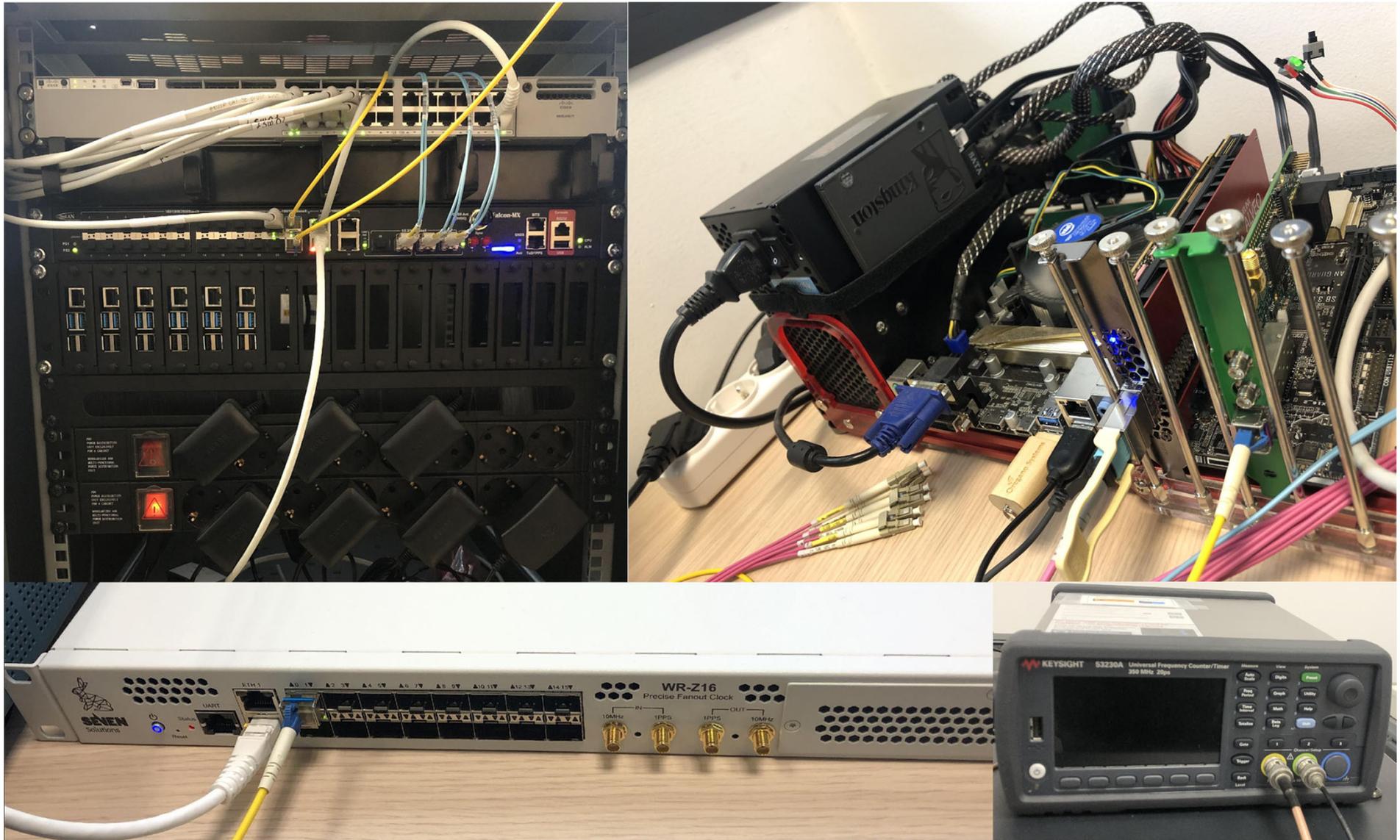- Shared medium with CODAC & Timing
- Cost effective

Experimental validation

- **Goals:** evaluate previous solution under realistic operating conditions (CODAC data traffic, hops, …).
- **Experimental considerations:**
  - **Physical time error measurement → PPS** (Pulse Per Second). Counters instead of software measures.
  - IEEE-1588v2 based on default protocol
  - **Utilization of time-unaware and time-aware switches** to evaluate synchronization quality over the data (CODAC) network.
- Technologies and equipment
  - **Chrony** implementation for NTP
  - **PTPd/Oregano stack** implementation for IEEE-1588v2.
  - **Fibrolan** as time-aware switches (IEEE-1588v2)
  - White Rabbit open hardware and Safran proprietary devices
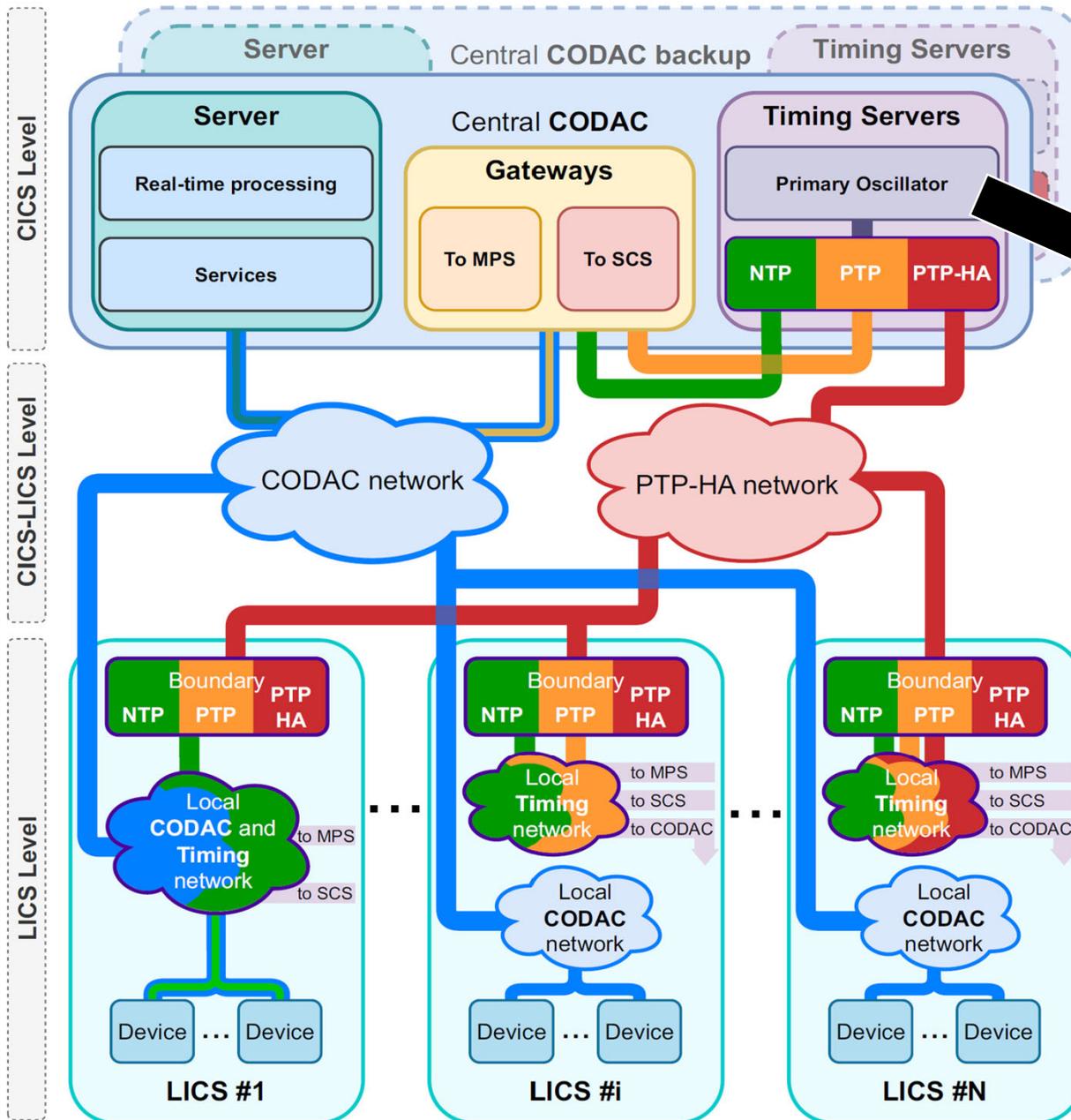 - **Tools:** Wireshark, packeth, iperf3, etc,
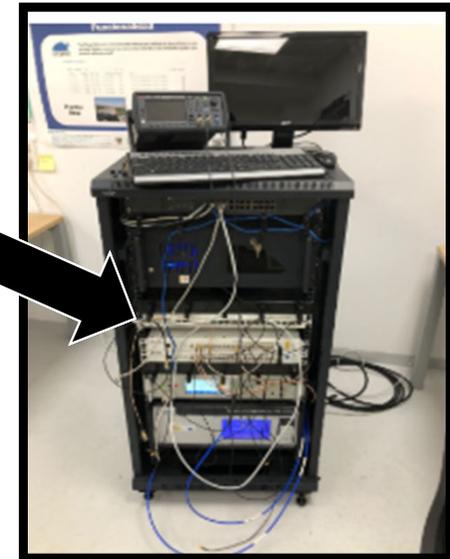
Setup configuration

Experimental results

- **NTP** and **White Rabbit technology** can perform well under any bandwidth utilization conditions

- **PTP**: see graph

Issue/requirement:

CODAC bandwidth ~20%

Computer Networks 233 (2023) 109807

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

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Ethernet-based timing system for accelerator facilities: The IFMIF-DONES case

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ARTICLE INFO

Keywords:
IFMIF-DONES
Network synchronization
Timing system
IEEE 1588
Network time protocol
White rabbit

ABSTRACT

This article presents the design of a timing system for accelerator facilities, which relies on a general networking approach based on standard Ethernet protocols that keeps all the devices synchronized to a common time reference. The case of the IFMIF-DONES infrastructure is studied in detail, providing a framework for the implementation of the timing system. The network time protocol (NTP) with software timestamping and the precision time protocol (PTP) with hardware timestamping are used to synchronize devices with sub-millisecond and sub-microsecond accuracy requirements, respectively. The design also considers the utilization of IEEE 1588 high accuracy default PTP profile (PTP-HA) to provide sub-nanosecond accuracy for the most demanding
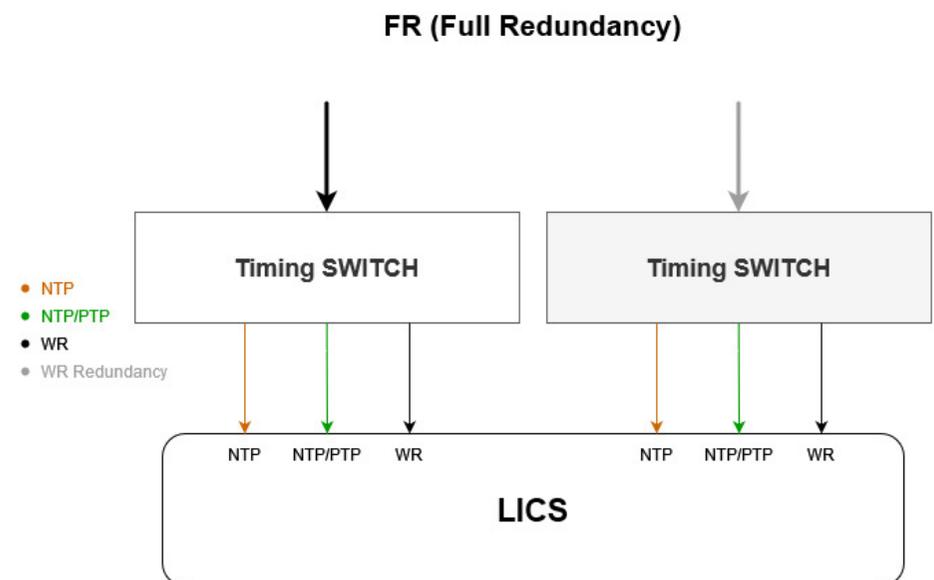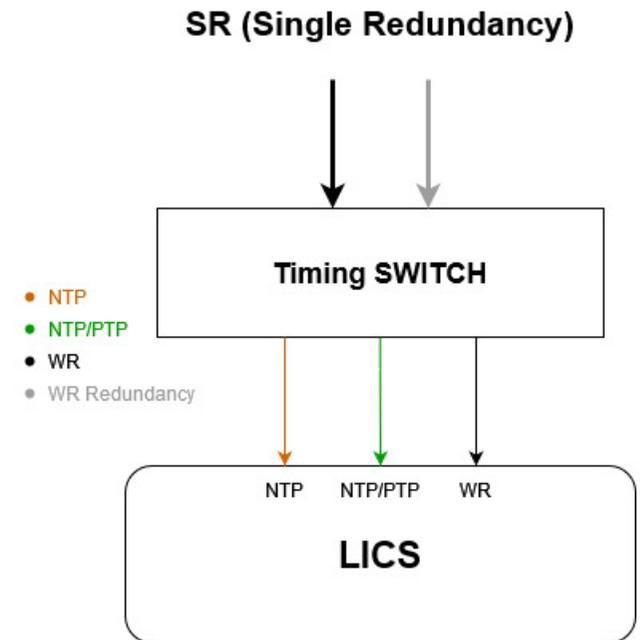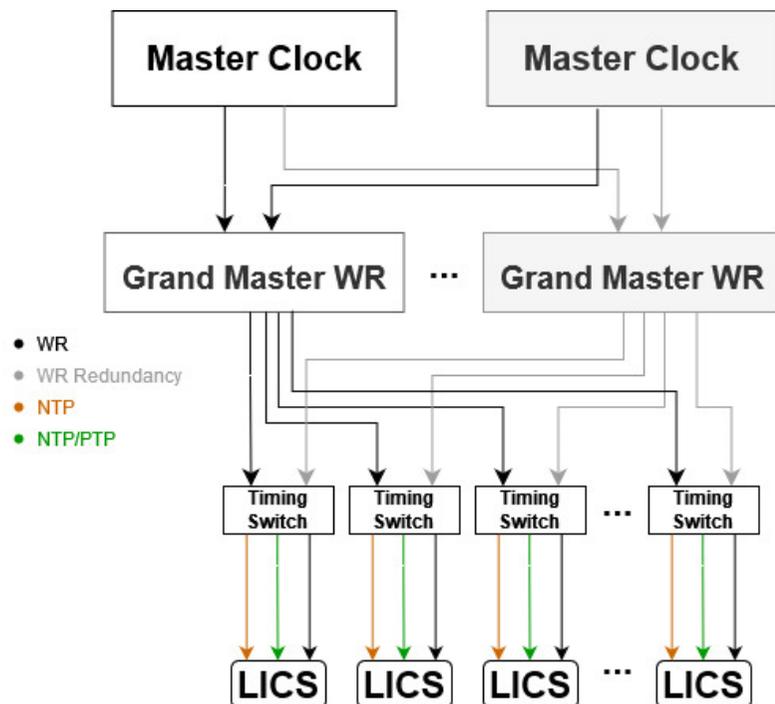
Sol. HA timing networks

- **Master clock**
- Dedicated network per HA (WR).
- No shared medium with data network
- Three time protocols only used at LICS

Timing network redundancy

- **Redundancy with PRP-like protocol at the Timing CISC.**
- Each timing device should receive two timing signals, each from a different grand master
- **LICS can implement single or full redundancy** depending on their dependability requirements

Final timing network

- 17 LICS with single redundancy and 12 with full redundancy.
- 41 switches and 58 WR ports. Therefore, with only 4 grand masters, PRP can be done. Note that GM mode can be implement with the timing switches (same device).
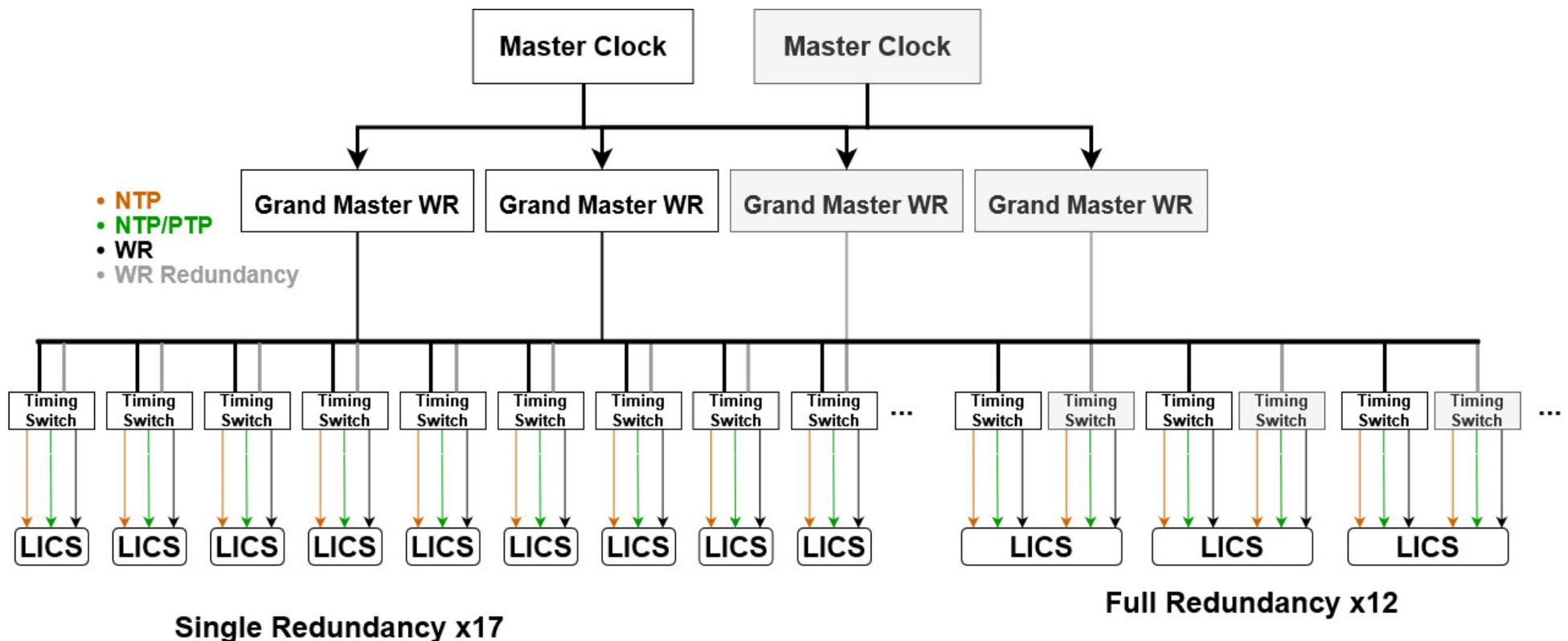
Conclusions

- A solution based on <u>standard Ethernet protocols</u> has been proposed for IFMIF-DONES. Easy to design and deploy, allow data and timing propagation on the same networks

- <u>A shared medium imposes significant constraints on the CODAC network operations</u>.

    - Experiments show that traffic above than 20% impact on the timing (unless careful timing design is used but flexibility requirement is not achieved)

- A solution based on **redundant network using HA/WR timing protocol** has been proposed for CISC. It offers minimal impact on cost without performance penalties.

- **Future work** will focus on the timestamping & trigger devices to be used on the edge network devices

Thanks for your attention

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